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Effects of Dwell-Time and Plunge Speed during Micro Friction Stir Spot Welding on Mechanical Properties of Thin Aluminum A1100 Welds

A.S. Baskoro[1,a*], Suwarsono[1], M.Dz.Habibullah[1], Z. Arvay[1], G. Kiswanto[1,b], Winarto[2,c], Z.W. Chen[3]

[1]Mechanical Engineering Department, Faculty of Engineering
[2]Metallurgical and Materials Engineering Department, Faculty of Engineering
Universitas Indonesia, Depok,Jawa Barat, Indonesia (16424)
[3] Department of Mechanical Engineering, Auckland University of Technology, New Zealand.

[a]ario@eng.ui.ac.id , [b]gandjar_kiswanto@eng.ui.ac.id.

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Abstract. Friction Stir Welding is a relatively new technique for joining metal. In some cases on aluminum joining, FSW gives better results compared with the arc welding processes, including the quality of welds and produces less distortion. The purpose of this study is to analyze the effect of high speed tool rotation on micro Friction Stir Spot Welding (μFSSW) to the shear fracture load of the welds. Response Surface Methods was used to analyze μFSSW parameters with the response. The welding material was Aluminum A1100, with thickness of 0.4 mm. The tool was made of HSS material which was shaped by micro grinding process. Tool shoulder diameter is 4 mm, and the pin diameter 1.5 mm with length of pin is 0.6 mm. The spindle speed is fixed at 33,000 rpm. The parameters that varied were the plunge speed (2 mm/min, 3 mm/min, 4 mm/min), and dwell time-1 (0 s, 2 s, 4 s) and variable of dwell time-2 (0 s, 2 s, 4 s). From the results of experiment and analysis, it is shown that the important welding parameter in high speed μFSSW process is dwell time-2.

Introduction

Recently, Friction stir welding (FSW) technology has been investigated intensively as it is a relatively new technique for metal joining. FSW as a new joining process for the aluminum is relatively simple, and in some cases has several advantages when compared with conventional joining process (e.g.: fusion welding process, riveting processes). FSW can be conducted by simply a milling machine or drilling machine after replacing appropriate tools, jigs and fixtures. Nowadays, the development of micro systems has been increasing in diversity for various applications. Miniaturization, high precision and high quality of mechanical devices are needed to construct more sophisticated microsystems [1]. As an alternative, FSW can be used in applications for thin metal sections connecting electronic, medical and micro equipment in order to keep damage from excessive heat [1]. For joining a thin aluminum plate (<1mm), FSW is commonly referred to as micro Friction Stir Welding (μFSW). For μFSW, ~~I~~it is necessary to study the jigging techniques, the parameters and their impacts on the quality of welds, surface quality and repeatability consistency of the welding results. The purpose of this study is to analyze the effects of dwell time and plunge speed–on the shear strength of welds made using μFSSW. Further analysis of the interaction between the welds properties and μFSW parameters to obtain the optimum response, was carried out by applying Response Surface Methodology (RSM).

During FSW, how fast the spindle is and how fast the tool travels have an important role and must be selected carefully to ensure a successful and efficient welding [2]. During the tool plunge, material displaced by the pin is fed into the cavity within the tool shoulder. This material serves as the start of a reservoir for the forging action of the shoulder. Forward movement of the tool forces new material into the cavity of the shoulder, pushing the existing material into the flow of the pin. Proper operation of this shoulder design requires tilting the tool 2° to 4° from the normal of the workpiece away from

the direction of travel; this is necessary to maintain the material reservoir and to enable the trailing edge of the shoulder tool to produce a compressive forging force on the weld [1].
The tool pin shape influences the flow of plasticized material. Tools used for FSSW experience only torsion due to rotational motion. This is different to the tools used for FSW process that experience both bending moment and torsion due to linear and rotational motion, respectively. Tozaki et al. [5] used cylindrical pins with 3 different pin lengths to understand the effect of tool geometry on the tensile shear strength in FSSW aluminum A6061-T4. It is shown that the tensile shear strength of the welds increased when longer tool pins. The weld microstructures vary depend on probe length, tool rotational speed and dwell time. Scialpi [2], Wang [3] and Baskoro [4] studied FSW on thin plate (thickness<1 mm).

Figure 1. Tools for μFSSW

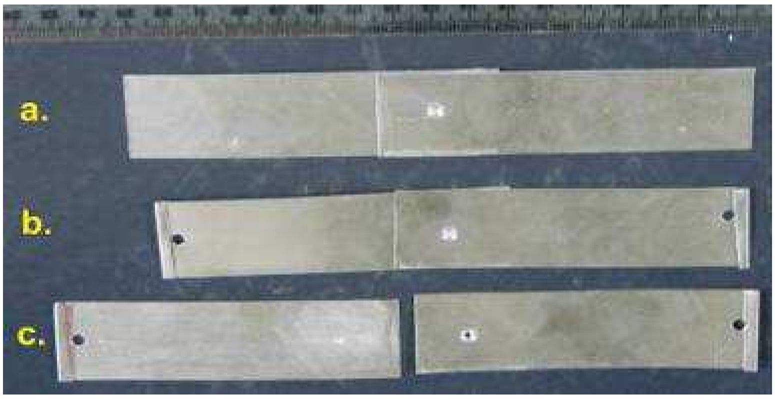


Figure 2, Specimen (a) after welding, (b)(c) before and after shear test

Methodology

This experiment studies the parameter effect of micro Friction Stir Spot Welding (μFSSW) process to the shear fracture load of the weld, in this case A1100 Aluminum material was used, with the thickness of 0.4 mm. The tool was made of HSS material and the pin was shaped by micro grinding. Tool shoulder diameter was 3 mm, with a cylindrical pin of 0^o angle and the length of pin 0.6 mm (Fig.1). The spindle speed was fixed at 33,000 rpm. Tool shoulder diameter was 4 mm, and the pin diameter 1.5 mm with length of pin was 0.6 mm (Fig.1). The μFSSW parameter variations used in this study were the variable of Plunge speed (2 mm/min, 3 mm/min, 4 mm/min), and the variable of Dwell time-1 (0 seconds , 2 seconds, 4 seconds) and the variable of Dwell time-2 (0 seconds , 2 seconds, 4 seconds). The dwell time was stopping plunge process for a while. Dwell time-1 and Dwell time-2 were stopping plunge process at 0.3 mm and 0.6 mm depth from surface. The variation of these parameters will affect to the mechanical properties (as the response), i.e. the tensile strength of welds joint. The specimens were aluminum sheet A1100 and cut into a size of 100 mm x 20 mm. At the welding process, the specimens were stacked with a width of 30 mm overlap.(Fig.2)

The machine that was used in the μFSSW process was a mini-drill machine, attached on a CNC Vertical Milling Machine. The holder of the specimen on the machine table with a fixture is shown in Fig. 3. To control the spindle speed of the mini grinder, digital photo tachometer was used and adjusted manually.

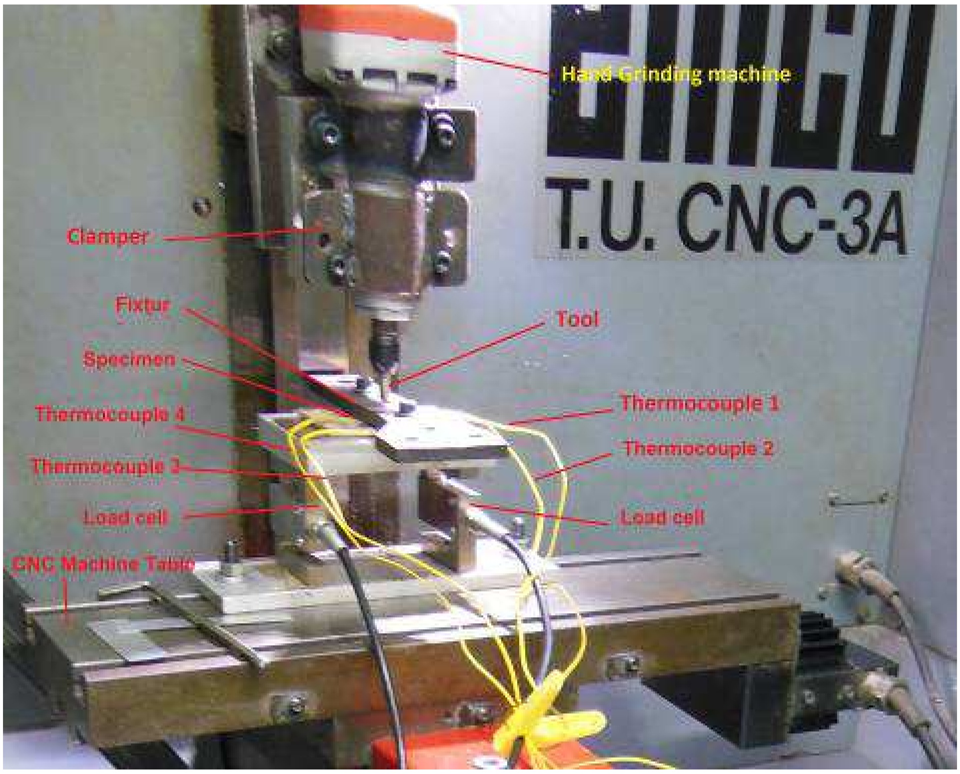


Figure 4. Fixture setup for holding aluminum plate

Weld specimens that have been processed, were cut using wire cutting, with a width of 25 mm, for shear-tensile testing. Tests were conducted using a tensile testing machine with a maximum load of 1,000 N and the testing speed was 5 mm/min. The tensile testing method follows JIS standard (JIS.2201-1999). Another instrument used for measuring temperature distribution was K-type thermocouple with diameter of 0.2 mm and Thermometer (Lutron 4-channel) (Fig. 4). All the data were collected by a Data Acquisition unit. The thermocouple's arrangement is shown in Fig. 5. An example of temperature distribution from DAQ is shown in Fig. 7. For measuring Z-force (axial force), type-S load cell was used.

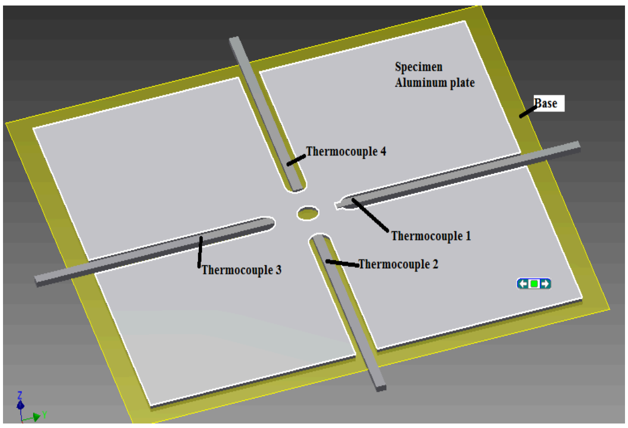


Figure 5. Thermocouples location at base plate

Result and Discussion

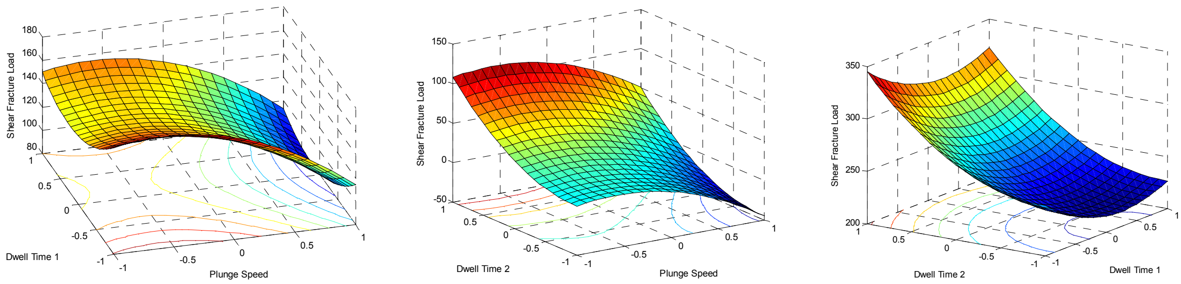
Input parameters of the welding process were Plunge Speed (A), Dwell Time-1 (B), and Dwell Time-2 (C). The responses of welding process were Temperature, Z-force and Shear Strength which is the peak shear load divided to pin section area. Designs of experiment (DoE) for µFSSW and parameters process are showed in Table 1. The response is the peak shear fracture load.

Table 1. DoE and Shear load of µFSSW

No.	Plunge Speed (mm/mint)	DwellTime1 (second)	DwellTime2 (second)	Shear Load (Newton)
1	2	0	0	171,08
2	2	0	2	230,66
3	2	0	4	271,62
4	2	2	0	101,59
5	2	2	2	175,53
6	2	2	4	259,43
7	2	4	0	165,75
8	2	4	2	97,54
9	2	4	4	392,40
10	3	0	0	149,63
11	3	0	2	244,30
12	3	0	4	228,16
13	3	2	0	197,06
14	3	2	2	126,10
15	3	2	4	276,98
16	3	4	0	163,38
17	3	4	2	236,02
18	3	4	4	170,67
19	4	0	0	140,05
20	4	0	2	125,38
21	4	0	4	243,22
22	4	2	0	94,21
23	4	2	2	165,50
24	4	2	4	150,90
25	4	4	0	97,22
26	4	4	2	133,08
27	4	4	4	202,46

The Response Surface Methods (RSM) analysis of shear test data produces Eq.1. Figure 6.a, 6.b, 6.c show the 2 parameters correlation to Shear load. From Eq. 1, Fig. 6.a and 6.c it is shown that parameters of **Plunge speed** (A) influences negatively to the response. In contrary, Fig. 5.b shows that **dwell time 2** (C) influences positively to response. Fig. 6.a & Fig. 6.b shows that **dwell time 1** (B) has little effect to the response. It shows that decreasing **Plunge speed** (A), will increases the tensile shear strength. The tensile shear strength increases with increasing **dwell time 2** (C). This means it needs to conduct further research toward a longer **dwell time 2**, and slower **plunge speed**.

$$Y_{ts}= 172.147-28.53xA-10.68xB+48.289xC-4.85xAxB-18.33xAxC+8.63xBxC-24.60x A^2+22.07xB^2+25.24xC^2 \quad (1)$$



a. Plunge Speed-dwell time 1 to Shear Load

b. Plunge Speed-dwell time 2 to Shear Load

c. Dwell time 1-dwell time 2 to Shear Load

Figure 6. RSM analysis of tensile strength

The tool plunging will influence to temperature and Z-force (Fig.7), because the friction between tool and specimen material will generate heat. The temperature chart has simillar form with the Z-force chart, which is increase at plunging time and decrease at dwell time. This phenomena means the dwell time-1 do not have significant influence as pre-heating on welding process. In the other side, dwell time-2 combined with z-force make welding joint better. Therefore, slower plunge speed and longer dwell time-2 will increase shear fracture load.

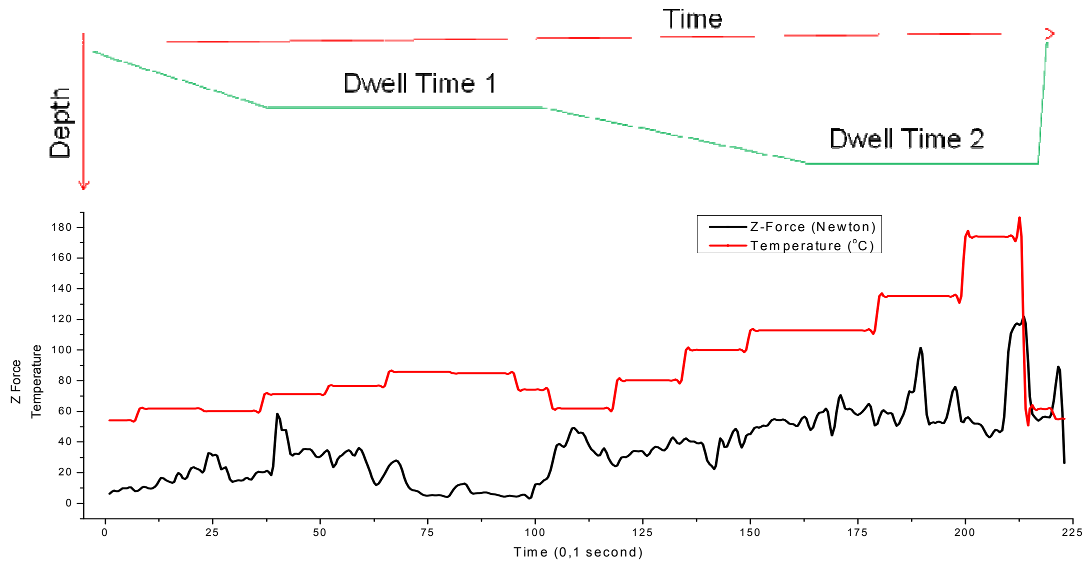


Figure 7. Plot of Z-Force and Temperature on tool Plunging process

Conclusion

Based on the results of the present experiments and analysis, it can be concluded that the important welding parameter in high rotation speed µFSSW process is Dwell time-2. Slower plunge speed increases the shear strength. For understanding the characteristics of this process, research on µFSSW needs to be done on a wider parameter range, and more variation of pin diameter.

Acknowledgment

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